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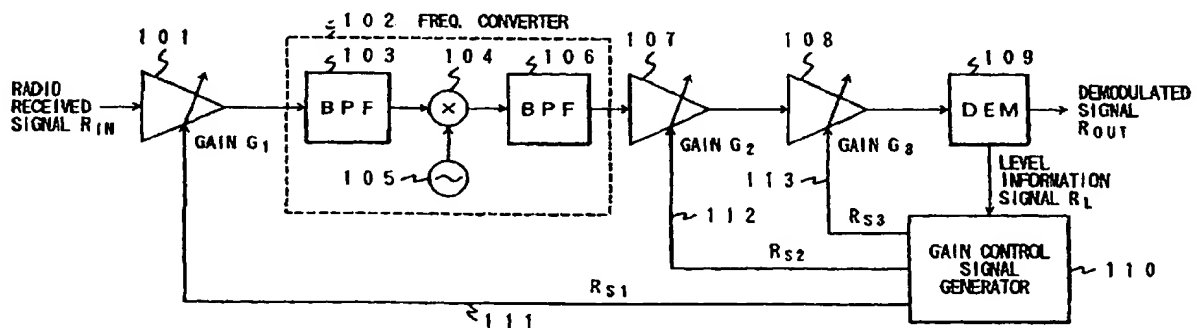
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(54) Variable gain control

(57) In a radio apparatus including a plurality of variable-gain amplifiers (101 and 107-108; 201-202 and 208) and at least one frequency converter (102, 203) which are connected in series, a gain controller includes a plurality of gain control lines (111-113, 210-212) and a

gain control signal generator (110, 209). The gain control lines are connected to the variable-gain amplifiers, respectively. The gain control signal generator individually generates a plurality of gain control signals which are supplied to the variable-gain amplifiers through the gain control lines, respectively.

FIG. 1



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Description

The present invention generally relates to automatic gain control (AGC) and, in particular, to gain controller and method for a plurality of variable-gain amplifiers which are used in a radio apparatus such as a radio receiver or a radio transmitter.

There has been disclosed a radio receiver including an AGC circuit which is designed to avoid distortion of an amplified signal and thereby improve a signal-to-noise ratio (S/N) in Japanese Patent examined Publication No. 3-24813. The radio receiver is provided with two radio-frequency (RF) variable gain amplifiers, a frequency converter, and an intermediate-frequency (IF) variable gain amplifier. The AGC circuit controls the respective gains of the RF amplifiers and the IF amplifier so as to keep the output signal level of the IF amplifier constant.

According to the conventional AGC circuit, the respective gains of the second RF amplifier and the IF amplifier are variable within different restricted gain ranges with respect to the output signal level of the IF amplifier. Referring to Fig. 4 of the above publication No. 3-24813, as the gain control signal Vc increases, the gains of the three amplifiers are sequentially reduced. More specifically, the gain of the IF amplifier is first reduced and then kept at a first reduced gain level. Since the gain of the IF amplifier is not reduced to below the first reduced gain level, in cases where the gain control signal Vc becomes further larger, the gain of the second RF amplifier is reduced and then kept at a second reduced gain level which is lower than the first reduced gain level. When the variable gain control signal Vc becomes furthermore larger, the gain of the first RF amplifier is finally reduced.

According to the conventional AGC as described above, however, as the radio received signal increases in level, a higher level of distortion occurs in the latter stage, that is, the frequency converter and the IF amplifier. In other words, even when the gain of the IF amplifier falls to the first reduced gain level, in cases where the first and second RF amplifiers are set to the maximum gain, the frequency converter receives a high level of RF signal from the second RF amplifier. Therefore, the IF amplifier also receives a high level of IF signal. This results in increased levels of distortion in the frequency converter and the IF amplifier.

It is possible to reduce distortion even in the case of high input level by increasing the chip areas of active devices or flowing larger current through transistors of output stages. However, such a method results in increased chip size and cost. Especially, in the case of battery-powered radio apparatuses, the larger power consumption, the shorter the life time of a battery.

Further, the conventional AGC circuit as described above has difficulty in providing electrical isolation among the RF and IF amplifiers. The reason is that these variable-gain amplifiers are controlled by a single control signal generated by a gain control signal gener-

ator. Needless to say, the higher the frequency and the input level, the lower the degree of isolation. Therefore, it is more difficult to provide electrical isolation between the first and second RF amplifiers. In addition, the single control signal is supplied to the RF and IF amplifiers through a single control line. This provides less isolation between them and, at worst, may cause the amplifiers to oscillate.

An object of the present invention is to provide a gain controller and a gain control method which achieves the stable amplification in a radio apparatus.

Another object of the present invention is to provide a gain controller and a gain control method which can reduce distortion in a radio apparatus without increasing the size and power consumption.

Still another object of the present invention is to provide a radio receiver and a radio transmitter which can improve the ratio of signal to noise with simplified circuit configuration.

According to an aspect of the present invention, in a radio apparatus which includes a plurality of variable-gain amplifiers and at least one frequency converter which are connected in series, a gain controller is comprised of a plurality of gain control lines connected to the variable-gain amplifiers, respectively, and a gain control signal generator for individually generating a plurality of gain control signals which are supplied to the variable-gain amplifiers through the gain control lines, respectively.

Since the gain control signals are individually supplied to the variable-gain amplifiers through the gain control lines, respectively, it can provide improved isolation between the variable-gain amplifiers and the effective prevention of malfunction such as undesired oscillation.

A frequency converter may be connected to a first stage for a relatively high frequency at one end and connected to a second stage for a relatively low frequency at the other end, each stage including at least one variable-gain amplifier. In this arrangement, the variable-gain amplifiers can individually vary in gain depending on the gain control signals, respectively, such that a variable-gain amplifier of the first stage decreases in gain before a variable-gain amplifier of the second stage does when the output signal increases in level to more than a predetermined level, and a variable-gain amplifier of the second stage increases in gain before a variable-gain amplifier of the first stage does when the output signal decreases in level to less than the predetermined level. Further, the first stage includes a first number of variable-gain amplifiers and the second stage includes a second number of variable-gain amplifiers, the first number being smaller than the second number.

The variable-gain amplifiers may individually vary in gain depending on the gain control signals, respectively, such that a leading variable-gain amplifier of the second stage decreases in gain before a variable-gain amplifier of the first stage does when the output signal

increases in level to more than a predetermined level, and a variable-gain amplifier of the first stage increases in gain before the leading variable-gain amplifier of the second stage when the output signal decreases in level to less than the predetermined level.

The variable-gain amplifiers may individually vary in gain depending on the gain control signals, respectively, such that the variable-gain amplifiers sequentially decrease in gain in order of a signal stream when the output signal increases in level to more than a predetermined level, and the variable-gain amplifiers sequentially increase in gain in the reverse order of the signal stream when the output signal increases in level to more than a predetermined level.

The variable-gain amplifiers may individually vary in gain depending on the gain control signals, respectively, such that the variable-gain amplifiers sequentially decrease in gain in the reverse order of a signal stream when the output signal increases in level to more than a predetermined level, and the variable-gain amplifiers sequentially increase in gain in the order of the signal stream when the output signal increases in level to more than a predetermined level.

The respective input levels of the variable-gain amplifiers provided downstream of the signal stream are prevented from becoming higher than is necessary. This results in effectively reduced distortion and power consumption and further simplified circuit configuration, which can achieve space and cost saving.

Fig. 1 is a block diagram showing a first embodiment of a gain control circuit applied to a radio receiver according to the present invention;

Fig. 2 is a graph showing a first embodiment of a gain control method applied to the radio receiver according to the present invention;

Fig. 3 is a graph showing a second embodiment of a gain control method applied to the radio receiver according to the present invention;

Fig. 4 is a block diagram showing a second embodiment of a gain control circuit applied to a radio transmitter according to the present invention;

Fig. 5 is a graph showing a third embodiment of a gain control method applied to the radio transmitter according to the present invention;

Fig. 6 is a block diagram showing a third embodiment of a gain control circuit applied to the radio transmitter according to the present invention;

Fig. 7A is a diagram showing an example of a variable gain amplifier used in the first, second and third embodiments of the gain control circuit;

Fig. 7B is a diagram showing another example of a variable gain amplifier used in the first, second and third embodiments of the gain control circuit;

Fig. 8 is a diagram showing an example of a demodulator used in the radio receiver;

Fig. 9 is a diagram showing an example of a gain control signal generator used in the first, second and third embodiments of the gain control circuit;

Fig. 10 is a diagram showing an example of a gain offset setting circuit used in the gain control signal generator of Fig. 9;

Fig. 11 is a diagram showing another example of a gain offset setting circuit used in the gain control signal generator of Fig. 9;

Fig. 12 is a diagram showing an example of a level information generator used in the radio transmitter of Fig. 6; and

Fig. 13 is a diagram showing another example of a level information generator used in the radio transmitter of Fig. 6.

GAIN CONTROL OF RECEIVER

Referring to Fig. 1, a radio receiver is provided with a first variable-gain amplifier 101 which amplifies a radio-frequency (RF) received signal R_{IN} by a controlled gain G_1 . The output of the first variable-gain amplifier 101 is converted to an intermediate-frequency (IF) signal by a frequency converter 102. The frequency converter 102 is comprised of a first band-pass filter 103, a mixer 104, a local oscillator 105 and a second band-pass filter 106. The first band-pass filter 103 passes only signals of a predetermined RF band through. The mixer 104 mixes the RF signal with a local oscillation signal generated by the local oscillator 105 to produce the IF signal through the second band-pass filter 106. The IF signal is of an intermediate frequency corresponding to the frequency difference between the RF signal and the local oscillation signal. The second band-pass filter 106 removes components of undesired frequencies from the IF signal.

The IF signal is amplified by a second variable-gain amplifier 107 by a controlled gain G_2 and is further amplified by a third variable-gain amplifier 108 by a controlled gain G_3 . After such an IF amplification, the IF signal is demodulated by a demodulator 109 into a demodulated signal R_{out} . The demodulator 109 includes a level information generator which generates level information of the IF signal using a predetermined threshold level S_{TH} to produce a level information signal R_L as will be described later. Based on the level information signal R_L received from the demodulator 109, a gain control signal

generator 110 generates a plurality of gain control signals R_{S1} - R_{S3} , which are individually controllable. More specifically, the gain control signal generator 110 is provided with three control lines 111, 112 and 113 which are connected to the variable-gain amplifiers 101, 107 and 108 to control their gains G_1 , G_2 and G_3 , respectively. These gains G_1 , G_2 and G_3 are controlled so that the input level of the demodulator 109 is kept constant.

It is here assumed that the respective gains G_1 , G_2 and G_3 of the variable-gain amplifiers 101, 107 and 108 increase as the respective levels of gain control signals R_{S1} - R_{S3} become higher and, contrarily, the respective gains G_1 , G_2 and G_3 decrease as the respective levels of gain control signals R_{S1} - R_{S3} become lower.

It is further assumed that the level information signal R_L increases as the level of the IF signal falls to less than the threshold level S_{TH} and, contrarily, the level information signal R_L decreases as the level of the IF signal rises to more than the threshold level S_{TH} . In other words, the level information signal R_L varies so that a variation of the level of the IF signal is canceled.

And, as the level information signal R_L increases and decreases in level, the respective levels of gain control signals R_{S1} - R_{S3} become higher or lower. Therefore, the gains G_1 , G_2 and G_3 individually increase and decrease as the level information signal R_L increases and decreases in level. Needless to say, the level information signal R_L may decrease and increase as the level of the IF signal rises and falls with respect to the threshold level S_{TH} and the gains G_1 , G_2 and G_3 individually increase and decrease as the level information signal R_L increases and decreases in level. The details will be described referring to Fig. 2 and Fig. 3.

FIRST EMBODIMENT OF GAIN CONTROL

As shown in Fig. 2, the gains G_1 , G_2 and G_3 vary with respect to the level information signal R_L within pre-determined gain ranges respectively. More specifically, in cases where the level of the IF signal rises to more than the threshold level S_{TH} , the level information signal R_L decreases as described above. While the level information signal R_L drops from a high level L_2 to a low level L_4 , the gains G_1 , G_2 and G_3 sequentially drop in the order presented. Firstly, the gain G_1 falls to a low level while the level information signal R_L drops from the level L_1 to a lower level L_2 as shown in Fig. 2(a), secondly the gain G_2 falls to a low level while the level information signal R_L drops from the level L_2 to a lower level L_3 as shown in Fig. 2(b), and finally the gain G_3 falls to a low level while the level information signal R_L drops from the level L_3 to a lower level L_4 as shown in Fig. 2(c). In other words, referring to Fig. 1, the variable-gain amplifiers 101, 107 and 108 decrease in gain in decreasing order of frequency.

Contrarily, referring to Fig. 2, while the level information signal R_L rises from the low level L_4 to the high level L_2 , the gains G_1 , G_2 and G_3 sequentially rise in the

reverse order presented. Firstly, the gain G_3 rises to a high level while the level information signal R_L rises from the level L_4 to the level L_3 as shown in Fig. 2(c), secondly the gain G_2 rises to a high level while the level information signal R_L rises from the level L_3 to the level L_2 as shown in Fig. 2(b), and finally the gain G_1 rises to a high level while the level information signal R_L rises from the level L_2 to the level L_1 as shown in Fig. 2(a). In other words, referring to Fig. 1, the variable-gain amplifiers 101, 107 and 108 increase in gain in ascending order of frequency.

In this manner, the overall gain of the variable-gain amplifiers 101, 107 and 108 is varied according to the level information signal R_L as shown in Fig. 2(d) so that the input level of the demodulator 109 is kept constant.

As described above, when the received signal R_{IN} increases in level to the extent of the signal-to-noise ratio (S/N) becoming insignificant, the gain control circuit of the radio receiver first lowers the gain G_1 of the first variable-gain amplifier 101. Therefore, the respective input levels of the frequency converter 102, the second variable-gain amplifier 107 and the third variable-gain amplifier 108 are prevented from becoming higher than is necessary. This results in effectively reduced distortion and power consumption and further simplified circuit configuration, which can achieve space and cost saving.

Further, according to the above embodiment, the gain control signals R_{S1} - R_{S3} are individually supplied to the variable-gain amplifiers 101, 107 and 108 through the control lines 111, 112 and 113, respectively. Such a configuration provides improved isolation between the variable-gain amplifiers and the effective prevention of malfunction such as undesired oscillation.

Furthermore, according to the above embodiment, the variable range of gain for IF signals is wider than that for RF signals. More specifically, the total variable range (Fig. 2(b) and (c)) of gains of the IF amplifiers 107 and 108 is wider than the variable range (Fig. 2(a)) of gain of the RF amplifier 101. This easily provides further improved isolation between the variable-gain amplifiers because a lower frequency generally reduces electromagnetic coupling.

SECOND EMBODIMENT OF GAIN CONTROL

As described above, when the received signal R_{IN} increases in level, the gain control circuit of the radio receiver first lowers the gain G_1 of the first variable-gain amplifier 101. This results in slightly degraded S/N at the input of the demodulator 109. Needless to say, when the received signal R_{IN} increases in level to such an extent that the respective input levels of the following stages are sufficiently high, the S/N problem can be negligible.

The S/N problem, however, comes up when the received signal R_{IN} reduces in level to such an extent that the S/N problem cannot be negligible and the input level

of the following frequency converter 102 does not increase to the extent of distortion occurring. In this case, the following gain control method can improve the S/N and reduce the distortion.

As shown in Fig. 3, the gains G_1 , G_2 and G_3 vary with respect to the level information signal R_L within predetermined gain ranges, respectively. While the level information signal R_L drops from a high level L_1 to a level L_4 , the gains G_2 , G_1 and G_3 sequentially drop in the order presented. Firstly, the gain G_2 falls to a low level while the level information signal R_L drops from the high level L_1 to a lower level L_2 as shown in Fig. 3(b), secondly the gain G_1 falls to a low level while the level information signal R_L drops from the level L_2 to a lower level L_3 as shown in Fig. 3(a), and finally the gain G_3 falls to a low level while the level information signal R_L drops from the level L_3 to a lower level L_4 as shown in Fig. 3(c). In other words, referring to Fig. 1, the IF variable-gain amplifier 107 first decreases in gain and then the IF variable-gain amplifier 108 decreases in gain. Finally, the RF variable-gain amplifier 101 decreases in gain.

Contrarily, referring to Fig. 3, while the level information signal R_L rises from the low level L_4 to the high level L_1 , the gains G_2 , G_1 and G_3 sequentially rise in the reverse order presented. Firstly, the gain G_3 rises to a high level while the level information signal R_L rises from the level L_4 to the level L_3 as shown in Fig. 3(c), secondly the gain G_1 rises to a high level while the level information signal R_L rises from the level L_3 to the level L_2 as shown in Fig. 3(a), and finally the gain G_2 rises to a high level while the level information signal R_L rises from the level L_2 to the level L_1 as shown in Fig. 3(b).

In this manner, the overall gain of the variable-gain amplifiers 101, 107 and 108 is varied according to the level information signal R_L as shown in Fig. 2(d) so that the input level of the demodulator 109 is kept constant.

As described above, according to the second embodiment, the second IF variable-gain amplifier 107 first decreases in gain in cases where the received signal R_{IN} reduces in level to such an extent that the S/N problem cannot be negligible and the input level of the frequency converter 102 does not increase to the extent of distortion occurring. Therefore, the S/N degradation and the signal distortion of the third variable-gain amplifier 108 are reduced. When the received signal R_{IN} increases in level to the extent of the S/N problem becoming negligible, the first RF variable-gain amplifier 101 decreases in gain, which can achieve improved S/N and reduced distortion.

GAIN CONTROL OF TRANSMITTER

Referring to Fig. 4, a radio transmitter is provided with a first and second variable-gain amplifiers 201 and 202 which are used to amplify IF signals. The first variable-gain amplifier 201 amplifies a transmission signal T_{IN} by a controlled gain G_1 and the second variable-

gain amplifier 202 further amplifies the output of the first variable-gain amplifier 201 by a controlled gain G_2 . The output of the second variable-gain amplifier 202 is converted to an RF signal by a frequency converter 203. The frequency converter 203 is comprised of a first band-pass filter 204, a mixer 205, a local oscillator 206 and a second band-pass filter 207. The first band-pass filter 204 passes only signals of a predetermined IF band through. The mixer 205 mixes the IF signal with a local oscillation signal generated by the local oscillator 206 to produce the RF signal through the second band-pass filter 207. The RF signal is of a radio frequency corresponding to the frequency difference between the IF signal and the local oscillation signal. The second band-pass filter 207 removes components of undesired frequencies from the RF signal. A third variable-gain amplifier 208 amplifies the RF signal by a controlled gain G_3 to produce a radio transmission signal T_{OUT} .

A gain control signal generator 209 generates a plurality of gain control signals T_{S1} - T_{S3} which are individually controllable based on a transmission level signal T_{S0} which is received from a transmission controller (not shown). More specifically, the gain control signal generator 209 is provided with three control lines 210, 211 and 212 which are connected to the variable-gain amplifiers 201, 202 and 208 to control their gains G_1 , G_2 and G_3 , respectively.

It is here assumed that the respective gains G_1 , G_2 and G_3 of the variable-gain amplifiers 201, 202 and 208 increase as the respective levels of gain control signals T_{S1} - T_{S3} become higher and, contrarily, the respective gains G_1 , G_2 and G_3 decrease as the respective levels of gain control signals T_{S1} - T_{S3} become lower. It is further assumed that the level of the radio transmission signal T_{OUT} increases as the transmission level signal T_{S0} becomes larger. In other words, the transmission controller varies the transmission level signal T_{S0} in level so that a variation of level of the RF transmission signal T_{OUT} is canceled and the level of the RF transmission signal T_{OUT} is kept constant because the transmission controller produces the transmission signal T_{IN} . The details will be described referring to Fig. 5.

As shown in Fig. 5, the gains G_1 , G_2 and G_3 vary with respect to the transmission level signal T_{S0} within predetermined gain ranges, respectively. More specifically, while the transmission level signal T_{S0} rises from the low level T_4 to the high level T_1 , the gains G_1 , G_2 and G_3 sequentially rise in the order presented. Firstly, the gain G_1 rises to a high level while the transmission level signal T_{S0} rises from the level T_4 to the level T_3 as shown in Fig. 5(a), secondly the gain G_2 rises to a high level while the transmission level signal T_{S0} rises from the level T_3 to the level T_2 as shown in Fig. 5(b), and finally the gain G_3 rises to a high level while the transmission level signal T_{S0} rises from the level T_2 to the level T_1 as shown in Fig. 5(c). In other words, referring to Fig. 4, the variable-gain amplifiers 201, 202 and 208 increase in gain in ascending order of frequency.

Contrarily, referring to Fig. 5, while the transmission level signal T_{S0} falls from the high level T_1 to the low level T_4 , the gains G_1 , G_2 and G_3 sequentially drop in the reverse order presented. Firstly, the gain G_3 drops to a low level while the transmission level signal T_{S0} lowers from the level T_1 to the level T_2 as shown in Fig. 5 (c), secondly the gain G_2 drops to a low level while the transmission level signal T_{S0} drops from the level T_2 to the level T_3 as shown in Fig. 5(b), and finally the gain G_1 drops to a low level while the transmission level signal T_{S0} drops from the level T_3 to the level T_4 as shown in Fig. 5(a). In other words, referring to Fig. 4, the variable-gain amplifiers 201, 202 and 208 decrease in gain in descending order of frequency.

In this manner, the overall gain of the variable-gain amplifiers 201, 202 and 208 is varied according to the transmission level signal T_{S0} as shown in Fig. 5(d) so that the level of the radio transmission signal T_{OUT} is kept constant.

As described above, the gain control circuit of the radio transmitter first lowers and finally raise the gain G_3 of the third variable-gain amplifier 208 to lower and increase the level of the radio transmission signal T_{OUT} . Since a large part of power consumption is made by the third variable-gain amplifier 208, the gain control circuit remarkably reduces in power consumption.

In addition, since the gain control circuit first lowers the gain G_3 of the third variable-gain amplifier 208 to lower the level of the radio transmission signal T_{OUT} , the level control of the radio transmission signal T_{OUT} is performed with minimizing the degradation of S/N. Such a gain control circuit provides advantages in communication systems with small transmission power, such as a CDMA (code division multiple access) system employing a direct sequence scheme.

Further, the gain control signals T_{S1} - T_{S3} are individually supplied to the variable-gain amplifiers 201, 202 and 208 through the control lines 210, 211 and 212, respectively. Such a configuration provides improved isolation between the variable-gain amplifiers and the effective prevention of malfunction such as undesired oscillation.

Furthermore, the variable range of gain for IF signals is wider than that for RF signals. More specifically, the total variable range (Fig. 5(a) and (b)) of gains of the IF amplifiers 201 and 202 is wider than the variable range (Fig. 5(c)) of gain of the RF amplifier 208. This easily provides further improved isolation between the variable-gain amplifiers because a lower frequency generally reduces electromagnetic coupling.

It is possible to set the respective variable-gain amplifiers 201, 202 and 208 to a gain of 0dB which means that they are each powered off. In the case where the respective variable-gain amplifiers 201, 202 and 208 can be powered off, the total power consumption of the transmitter is dramatically reduced by applying the control method as shown in Fig. 5.

Referring to Fig. 6, where circuit blocks similar to

those previously described with reference to Fig. 4 are denoted by the same reference numerals, a radio transmitter is provided with a transmission level detector 213 which is connected to the output of the third variable-gain amplifier 208. The transmission level detector 213 produces a detected transmission level signal T_L from the radio transmission signal T_{OUT} and feeds it back to the transmission controller (not shown). The transmission controller receives the detected transmission level signal T_L and makes a correction to the transmission level signal T_{S0} using the detected transmission level signal T_L . The gain control signal generator 209, as described before, generates the gain control signals T_{S1} - T_{S3} which are individually controllable based on the corrected transmission level signal T_{S0} which is received from the transmission controller. The correction of the transmission level signal T_{S0} is performed when the level of the radio transmission signal T_{OUT} increases to such an extent that the transmission level signal T_L can be accurately detected.

It is here assumed that the respective gains G_1 , G_2 and G_3 of the variable-gain amplifiers 201, 202 and 208 increase as the respective levels of gain control signals T_{S1} - T_{S3} become higher and, contrarily, the respective gains G_1 , G_2 and G_3 decrease as the respective levels of gain control signals T_{S1} - T_{S3} become lower. It is further assumed that the level of the radio transmission signal T_{OUT} increases as the transmission level signal T_{S0} becomes larger. In other words, the transmission controller varies the corrected transmission level signal T_{S0} in level so that a variation of level of the RF transmission signal T_{OUT} is canceled.

In this transmitter, the gain control as shown in Fig. 5 is also performed. The gains G_1 , G_2 and G_3 vary with respect to the corrected transmission level signal T_{S0} within predetermined gain ranges, respectively. More specifically, while the corrected transmission level signal T_{S0} rises from the low level T_4 to the high level T_1 , the gains G_1 , G_2 and G_3 sequentially rise in the order presented. Firstly, the gain G_1 rises to a high level while the corrected transmission level signal T_{S0} rises from the level T_4 to the level T_3 as shown in Fig. 5(a), secondly the gain G_2 rises to a high level while the corrected transmission level signal T_{S0} rises from the level T_3 to the level T_2 as shown in Fig. 5(b), and finally the gain G_3 rises to a high level while the corrected transmission level signal T_{S0} rises from the level T_2 to the level T_1 as shown in Fig. 5(c). In other words, referring to Fig. 6, the variable-gain amplifiers 201, 202 and 208 increase in gain in ascending order of frequency.

Contrarily, referring to Fig. 5, while the corrected transmission level signal T_{S0} falls from the high level T_1 to the low level T_4 , the gains G_1 , G_2 and G_3 sequentially drop in the reverse order presented. Firstly, the gain G_3 drops to a low level while the corrected transmission level signal T_{S0} lowers from the level T_1 to the level T_2 as shown in Fig. 5(c), secondly the gain G_2 drops to a low level while the corrected transmission level signal T_{S0}

drops from the level T_2 to the level T_3 as shown in Fig. 5(b), and finally the gain G_1 drops to a low level while the corrected transmission level signal T_{S0} drops from the level T_3 to the level T_4 as shown in Fig. 5(a). In other words, referring to Fig. 6, the variable-gain amplifiers 201, 202 and 208 decrease in gain in descending order of frequency.

In this manner, the overall gain of the variable-gain amplifiers 201, 202 and 208 is varied according to the corrected transmission level signal T_{S0} as shown in Fig. 5(d) so that the level of the radio transmission signal T_{OUT} is kept constant. Since the transmission level signal T_L is fed back to be used to correct the transmission level signal T_{S0} , a more accurate level control of the radio transmission signal T_{OUT} can be achieved.

Further, the gain control circuit of the radio transmitter first lowers and finally raise the gain G_3 of the third variable-gain amplifier 208 to lower and increase the level of the radio transmission signal T_{OUT} . Since a large part of power consumption is made by the third variable-gain amplifier 208, the gain control circuit remarkably reduces in power consumption. In addition, since the gain control circuit first lowers the gain G_3 of the third variable-gain amplifier 208 to lower the level of the radio transmission signal T_{OUT} the level control of the radio transmission signal T_{OUT} is performed with minimizing the degradation of S/N. Such a gain control circuit provides advantages in communication systems with small transmission power as described before.

It should be noted that the correction of the transmission level signal T_{S0} is not performed when the level of the radio transmission signal T_{OUT} decreases to such an extent that the transmission level signal T_L cannot be accurately detected. In such a case, the transmission controller supplies the transmission level signal T_{S0} to the gain control signal generator 209 as in the case of Fig. 4.

DETAILS OF CIRCUITS

VARIABLE-GAIN AMPLIFIER

A variable-gain amplifier as shown in Figs. 1, 4 and 6 may be comprised of a variable attenuator and a fixed-gain amplifier which are connected in series.

Referring to Fig. 7A, the variable attenuator 301 receives an input signal V_i and attenuates it according to the gain control signal. The output of the variable attenuator 301 is then amplified by the fixed-gain amplifier 302. In this arrangement, the gain control is performed by the variable attenuator 301 before amplification. Therefore, even when the input signal V_i becomes larger in level, the input level of the fixed-gain amplifier 302 is restricted, resulting in reduced distortion in the fixed-gain amplifier 302.

Referring to Fig. 7B, the fixed-gain amplifier 401 amplifies an input signal V_i before the variable attenuator 402 attenuates the amplified input signal according

to the gain control signal. In this arrangement, since the gain control is performed after amplification, the degradation of S/N is prevented.

5 DEMODULATOR

Referring to Fig. 8, the demodulator 109 as shown in Fig. 1 may include a demodulator 501 and a level information generator which is comprised of a subtractor 502 and an integrator 503. In the level information generator, the subtractor 502 subtracts the IF signal from the threshold level S_{TH} and the integrator 503 integrates the result to produce the level information signal R_L . Since the integrator 503 integrates negative values when the level of the IF signal is greater than the threshold level S_{TH} and positive values when the level of the IF signal is smaller than the threshold level S_{TH} , the level information signal R_L varies in level until the level of the IF signal is equal to the threshold level S_{TH} .

20 GAIN CONTROL SIGNAL GENERATOR

Referring to Fig. 9, the gain control signal generator includes a plurality of gain offset setting circuits 601-603. The respective gain offset setting circuits receive a level information signal V_L and produce gain control signals V_{S1} - V_{S3} . The level information signal V_L is the level information signal R_L or the transmission level signal T_{S0} and the gain control signals V_{S1} - V_{S3} are the gain control signals R_{S1} - R_{S3} or T_{S1} - T_{S3} in the above embodiments. The respective gain offset setting circuits 601-603 provide different offset amounts of gain and the same slope of gain characteristic as shown in Figs. 2, 3 and 5, where the offset amount of gain is set to provide a shift of starting and terminating points of gain variation.

Referring to Fig. 10, each gain offset setting circuit may be comprised of two inverting amplifiers which are connected in series to form a non-inverting amplifier. The controlled gain G of the corresponding variable-gain amplifier is determined based on the ratio of resistances R_1 and R_2 and the ratio of resistances R_5 and R_6 . The offset amount of gain is determined based on the applied voltage V , the ratio of resistances R_3 and R_4 , and the ratio of resistances R_7 and R_8 .

Referring to Fig. 11, each gain offset setting circuit may be comprised of one inverting amplifier. In this case, the higher the level information signal V_L , the lower the gain of the corresponding variable-gain amplifier. Therefore, in the case where the level information signal V_L increases as the level of the IF signal of the receiver as shown in Fig. 1 becomes higher or where the corresponding variable-gain amplifier reduces in gain as the level of the gain control signal becomes higher, the gain offset setting circuit of the inverting amplifier is usable.

55 TRANSMISSION LEVEL DETECTOR

Referring to Fig. 12, the transmission level detector

213 of the radio transmitter may be comprised of a diode D_{20} for half-wave rectification and a smoothing circuit comprising a resistor R_{20} , a capacitor C_{20} and a resistor R_{21} . The diode D_{20} rectifies the radio transmission signal T_{OUT} and the rectified signal is smoothed to the transmission level signal T_L .

Referring to Fig. 13, the transmission level detector 213 of the radio transmitter may be comprised of a diode D_{30} for half-wave rectification and a smoothing circuit comprising a resistor R_{30} , a capacitor C_{30} and a resistor R_{31} . The transmission level detector 213 is further provided with an inductor L_{30} through which a fixed voltage $+v$ is applied to the anode A of the diode D_{30} . The diode D_{30} rectifies the radio transmission signal T_{OUT} and the rectified signal is smoothed to the transmission level signal T_L . Since a constant direct bias is applied to the anode of the diode D_{30} through the inductor L_{30} , the inductor L_{30} is capable of suppressing degradation of level detection sensitivity caused by a forward voltage drop of the diode D_{30} .

Claims

1. A gain controller for controlling a level of an output signal of a radio apparatus which includes a plurality of variable-gain amplifiers (101, 107-108, 201-202 and 208) and at least one frequency converter (102, 203) which are connected in series, characterized by:
 - a plurality of gain control lines (111-113, 210-212) connected to the variable-gain amplifiers, respectively; and
 - a gain control signal generator (110, 209) for individually generating a plurality of gain control signals which are supplied to the variable-gain amplifiers through the gain control lines, respectively.
2. The gain controller according to claim 1, wherein a frequency converter is connected to a first stage (101, 208) for a relatively high frequency at one end and is connected to a second stage (107-108, 201-202) for a relatively low frequency at the other end, each stage including at least one variable-gain amplifier,
 - wherein the variable-gain amplifiers individually vary in gain depending on the gain control signals, respectively, such that a variable-gain amplifier of the first stage decreases in gain before a variable-gain amplifier of the second stage does when the output signal increases in level to more than a predetermined level, and a variable-gain amplifier of the second stage increases in gain before a variable-gain amplifier of the first stage does when the output signal decreases in level to less than the predetermined level.
3. The gain controller according to claim 1, wherein a frequency converter is connected to a first stage for a relatively high frequency at one end and is connected to a second stage for a relatively low frequency at the other end, each stage including at least one variable-gain amplifier, a variable range of gain in the second stage being wider than that in the first stage.
4. The gain controller according to claim 1, wherein the first stage includes a first number of variable-gain amplifiers and the second stage includes a second number of variable-gain amplifiers, the first number being smaller than the second number.
5. The gain controller according to claim 1, wherein a frequency converter is connected to a first stage for a relatively high frequency at one end and is connected to a second stage for a relatively low frequency at the other end, each stage including at least one variable-gain amplifier,
 - wherein the variable-gain amplifiers individually vary in gain depending on the gain control signals, respectively, such that a leading variable-gain amplifier of the second stage decreases in gain before a variable-gain amplifier of the first stage does when the output signal increases in level to more than a predetermined level, and a variable-gain amplifier of the first stage increases in gain before the leading variable-gain amplifier of the second stage when the output signal decreases in level to less than the predetermined level.
6. The gain controller according to claim 1, wherein the variable-gain amplifiers individually vary in gain depending on the gain control signals, respectively, such that the variable-gain amplifiers sequentially decrease in gain in order of a signal stream when the output signal increases in level to more than a predetermined level, and the variable-gain amplifiers sequentially increase in gain in the reverse order of the signal stream when the output signal increases in level to more than a predetermined level.
7. The gain controller according to claim 1, wherein the variable-gain amplifiers individually vary in gain depending on the gain control signals, respectively, such that the variable-gain amplifiers sequentially decrease in gain in the reverse order of a signal stream when the output signal increases in level to more than a predetermined level, and the variable-gain amplifiers sequentially increase in gain in the order of the signal stream when the output signal increases in level to more than a predetermined level.
8. A gain control method for controlling a level of an output signal of a radio apparatus which includes a

plurality of variable-gain amplifiers (101, 107-108, 201-202 and 208) and at least one frequency converter (102, 203) which are connected in series, characterized by the steps of:

- a) generating a plurality of gain control signals corresponding to the variable-gain amplifiers, respectively, based on the level of the output signal; and
- b) individually varying the variable-gain amplifiers in gain according to the gain control signals, respectively, so that the level of the output signal is kept at a predetermined level.

9. The gain control method according to claim 8, wherein a frequency converter is connected to a first stage for a relatively high frequency at one end and is connected to a second stage for a relatively low frequency at the other end, each stage including at least one variable-gain amplifier,

the step b) comprising the steps of:
decreasing a gain of a variable-gain amplifier of the first stage before decreasing a gain of a variable-gain amplifier of the second stage when the output signal increases in level to more than a predetermined level; and
increasing a gain of a variable-gain amplifier of the second stage before increasing a gain of a variable-gain amplifier of the first stage when the output signal decreases in level to less than the predetermined level.

10. The gain control method according to claim 8, wherein a frequency converter is connected to a first stage for a relatively high frequency at one end and is connected to a second stage for a relatively low frequency at the other end, each stage including at least one variable-gain amplifier, a variable range of gain in the second stage being wider than that in the first stage.

11. The gain control method according to claim 8, wherein a frequency converter is connected to a first stage for a relatively high frequency at one end and is connected to a second stage for a relatively low frequency at the other end, each stage including at least one variable-gain amplifier,

the step b) comprising the steps of:
decreasing a gain of a leading variable-gain amplifier of the second stage before decreasing a gain of a variable-gain amplifier of the first stage when the output signal increases in level to more than a predetermined level; and
increasing a gain of a variable-gain amplifier of the first stage before increasing a gain of the leading variable-gain amplifier of the second

stage when the output signal decreases in level to less than the predetermined level.

12. The gain control method according to claim 8, wherein the step b) comprises the steps of:

sequentially decreasing the variable-gain amplifiers in gain in order of a signal stream when the output signal increases in level to more than a predetermined level; and
sequentially increasing the variable-gain amplifiers in gain in the reverse order of the signal stream when the output signal increases in level to more than a predetermined level.

13. The gain control method according to claim 8, wherein the step b) comprises the steps of:

sequentially decreasing the variable-gain amplifiers in gain in the reverse order of a signal stream when the output signal increases in level to more than a predetermined level; and
sequentially increasing the variable-gain amplifiers in gain in the order of the signal stream when the output signal increases in level to more than a predetermined level.

14. A receiver comprising:

a frequency converter (102) for converting a relatively high frequency signal into a relatively low frequency signal;
a plurality of variable-gain amplifiers (101, 107, 108) connected in series to the frequency converter which follows a first stage (101) including at least one first variable-gain amplifier and is followed by a second stage (107, 108) including at least one second variable-gain amplifier, and a level detector (109) for detecting a level of an output signal of the second stage to produce a level information signal,
characterized by:

a gain controller (110) for individually generating a plurality of gain control signals based on the level information signal, the gain control signals being supplied to the variable-gain amplifiers through a plurality of gain control lines (111-113), respectively.

15. The receiver according to claim 14, wherein the variable-gain amplifiers individually vary in gain depending on the gain control signals, respectively, such that the variable-gain amplifiers sequentially decrease in gain in the order of a received signal stream when the output signal increases in level to more than a predetermined level, and the variable-gain amplifiers sequentially increase in gain in the reverse order of the received signal stream when

the output signal increases in level to more than a predetermined level.

16. The receiver according to claim 14, wherein the variable-gain amplifiers individually vary in gain depending on the gain control signals, respectively, such that a leading variable-gain amplifier of the second stage decreases in gain before a variable-gain amplifier of the first stage does when the output signal increases in level to more than a predetermined level, and a variable-gain amplifier of the first stage increases in gain before the leading variable-gain amplifier of the second stage when the output signal decreases in level to less than the predetermined level.

17. A transmitter comprising:

a frequency converter (203) for converting a relatively low frequency signal into a relatively high frequency signal; and
a plurality of variable-gain amplifiers (201, 202, 208) connected in series to the frequency converter which follows a first stage (201, 202) including at least one first variable-gain amplifier and is followed by a second stage (208) including at least one second variable-gain amplifier,
characterized by:
a gain controller (209) for individually generating a plurality of gain control signals based on a transmission level signal, the gain control signals being supplied to the variable-gain amplifiers through a plurality of gain control lines (210-212), respectively.

18. The transmitter according to claim 17, wherein the variable-gain amplifiers individually vary in gain depending on the gain control signals, respectively, such that the variable-gain amplifiers sequentially decrease in gain in the reverse order of a stream of the transmission signal when the transmission signal increases in level to more than a predetermined level, and the variable-gain amplifiers sequentially increase in gain in the order of the stream when the transmission signal increases in level to more than a predetermined level.

19. The transmitter according to claim 17, further comprising:
a transmission controller for adjusting the transmission level signal so as to keep an output signal of the second stage at a predetermined constant level.

20. The transmitter according to claim 17, further comprising:

a transmission level detector (213) for detecting an output level from an output signal of the second stage; and

a transmission controller for adjusting the transmission level signal using the output level so as to keep an output signal of the second stage at a predetermined constant level.

FIG. 1

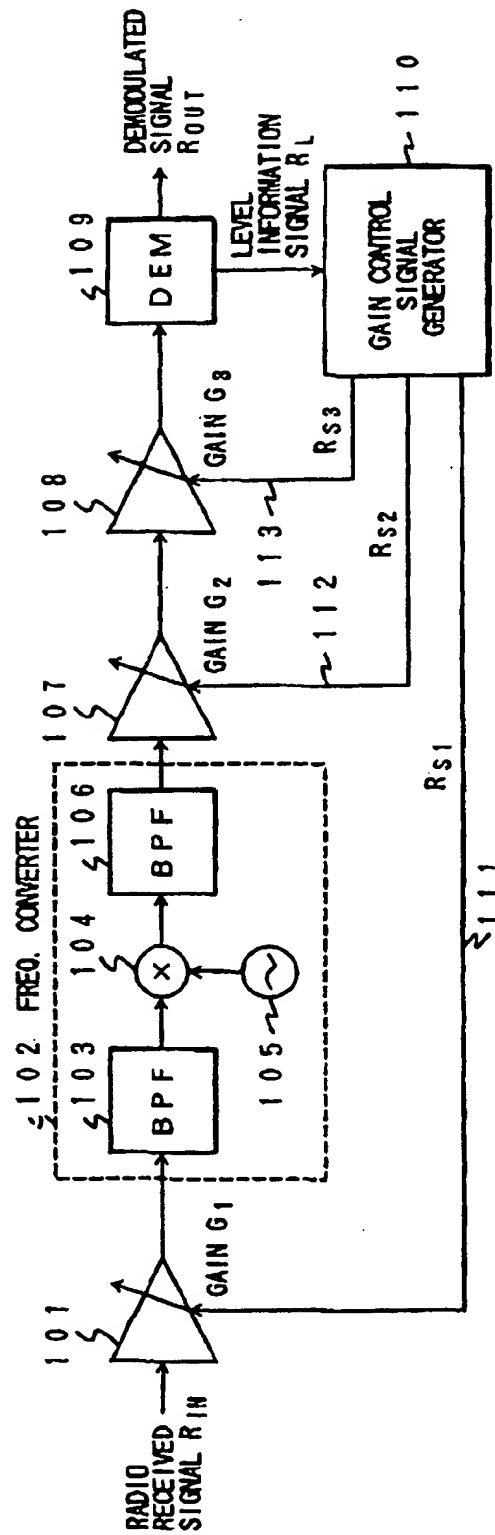


FIG.2

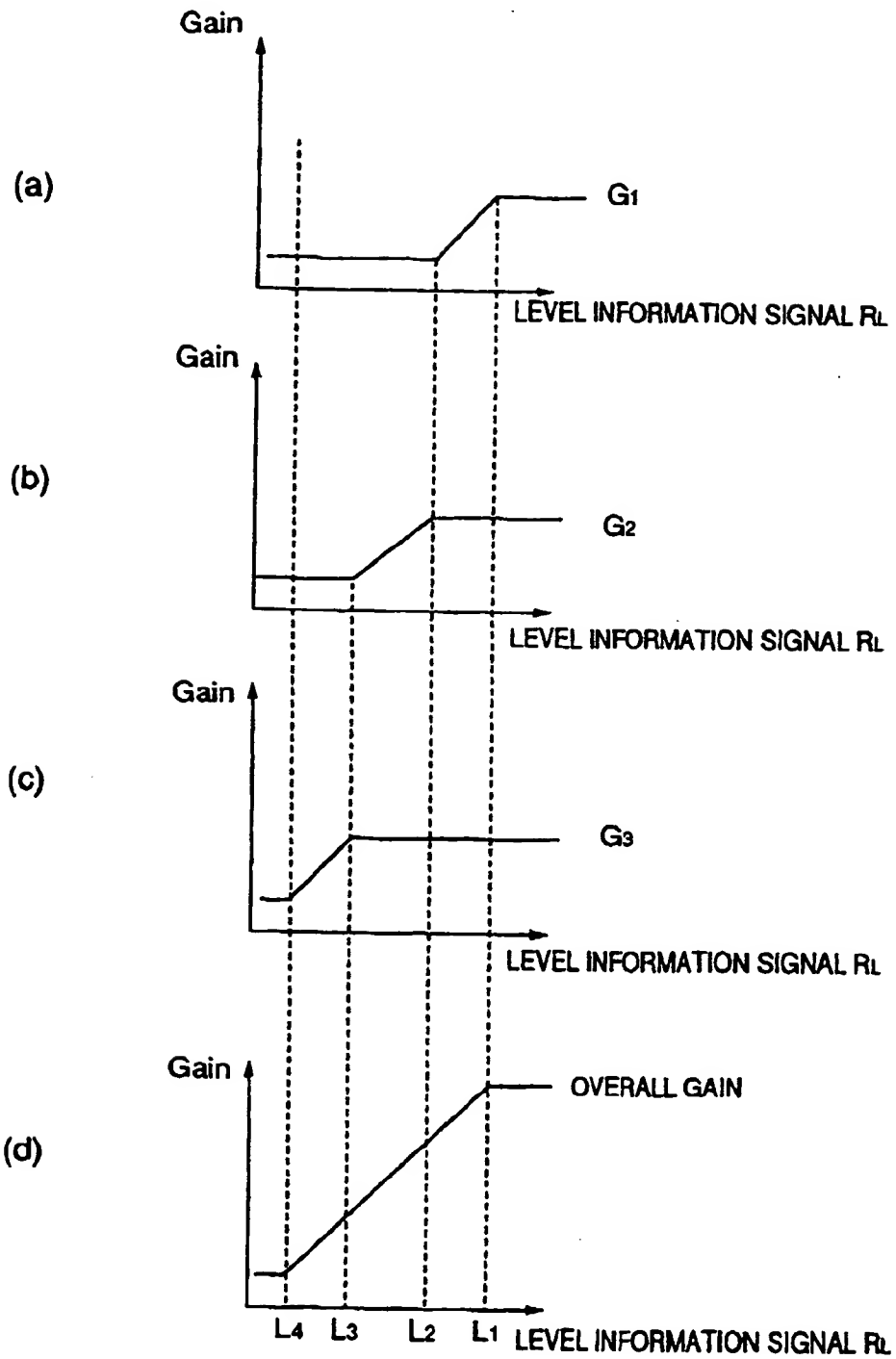


FIG.3

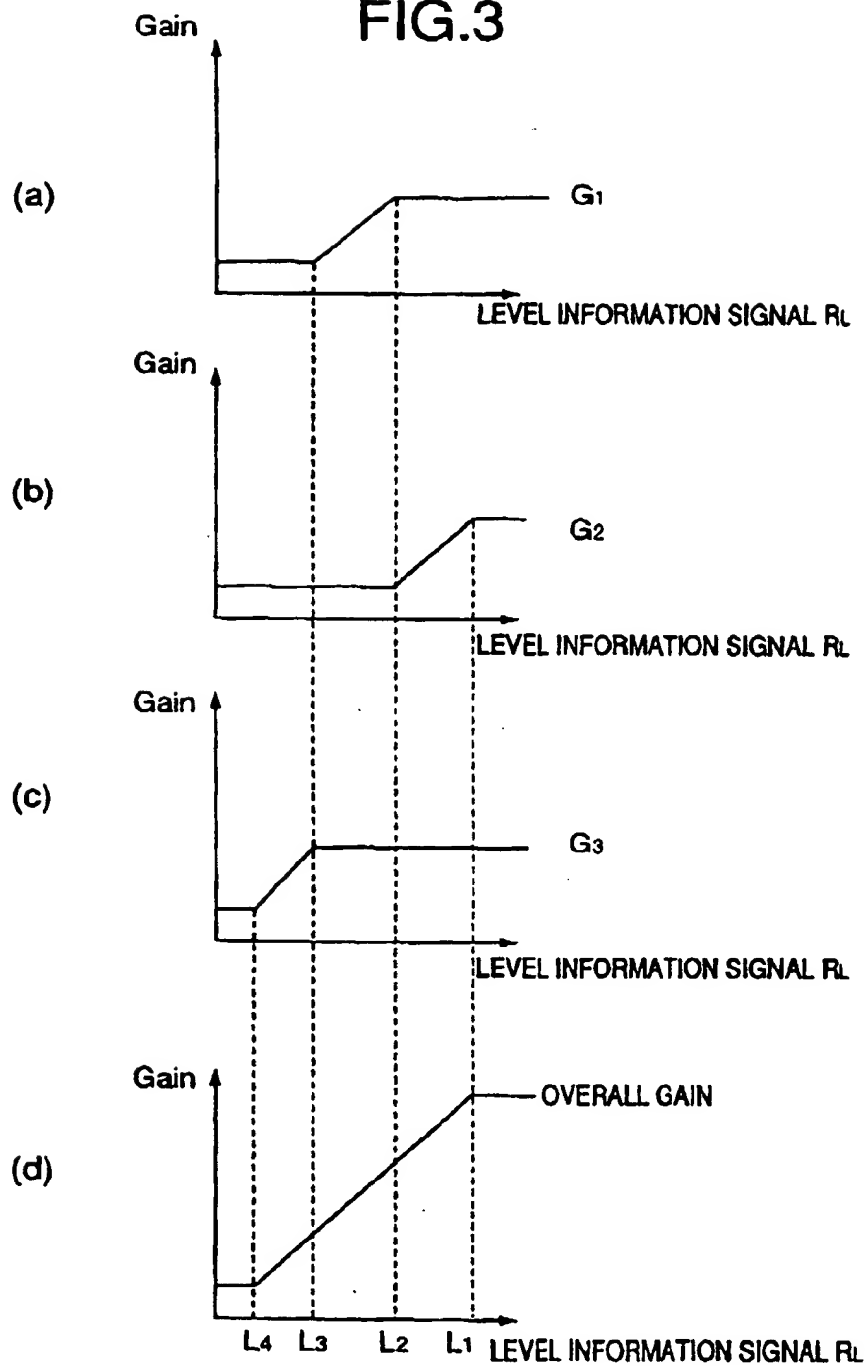


FIG. 4

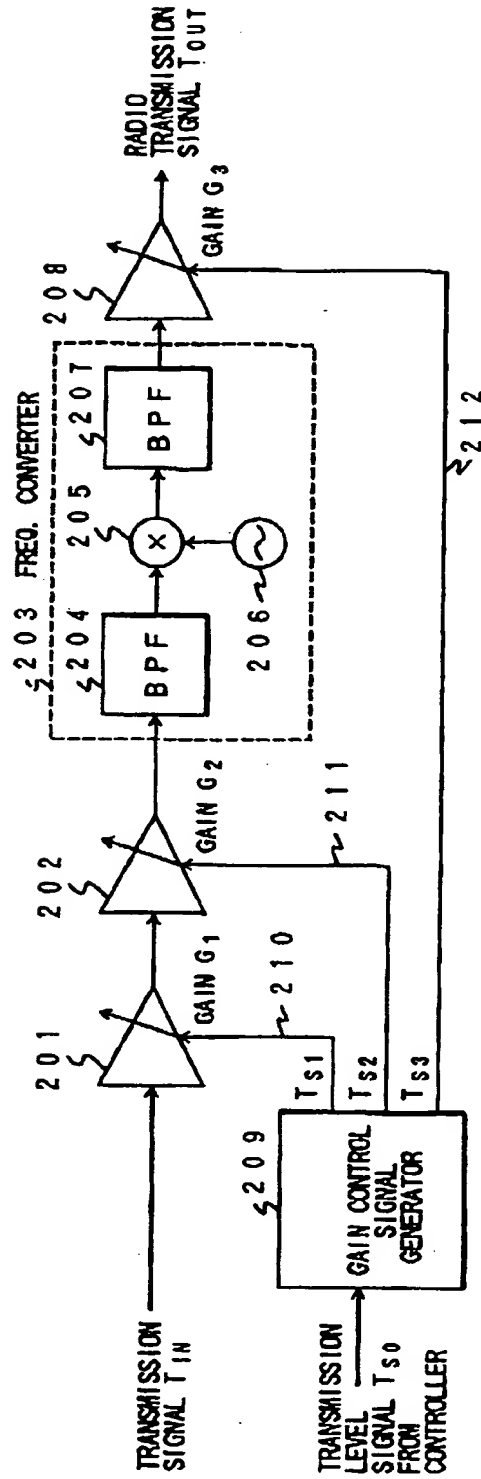


FIG.5

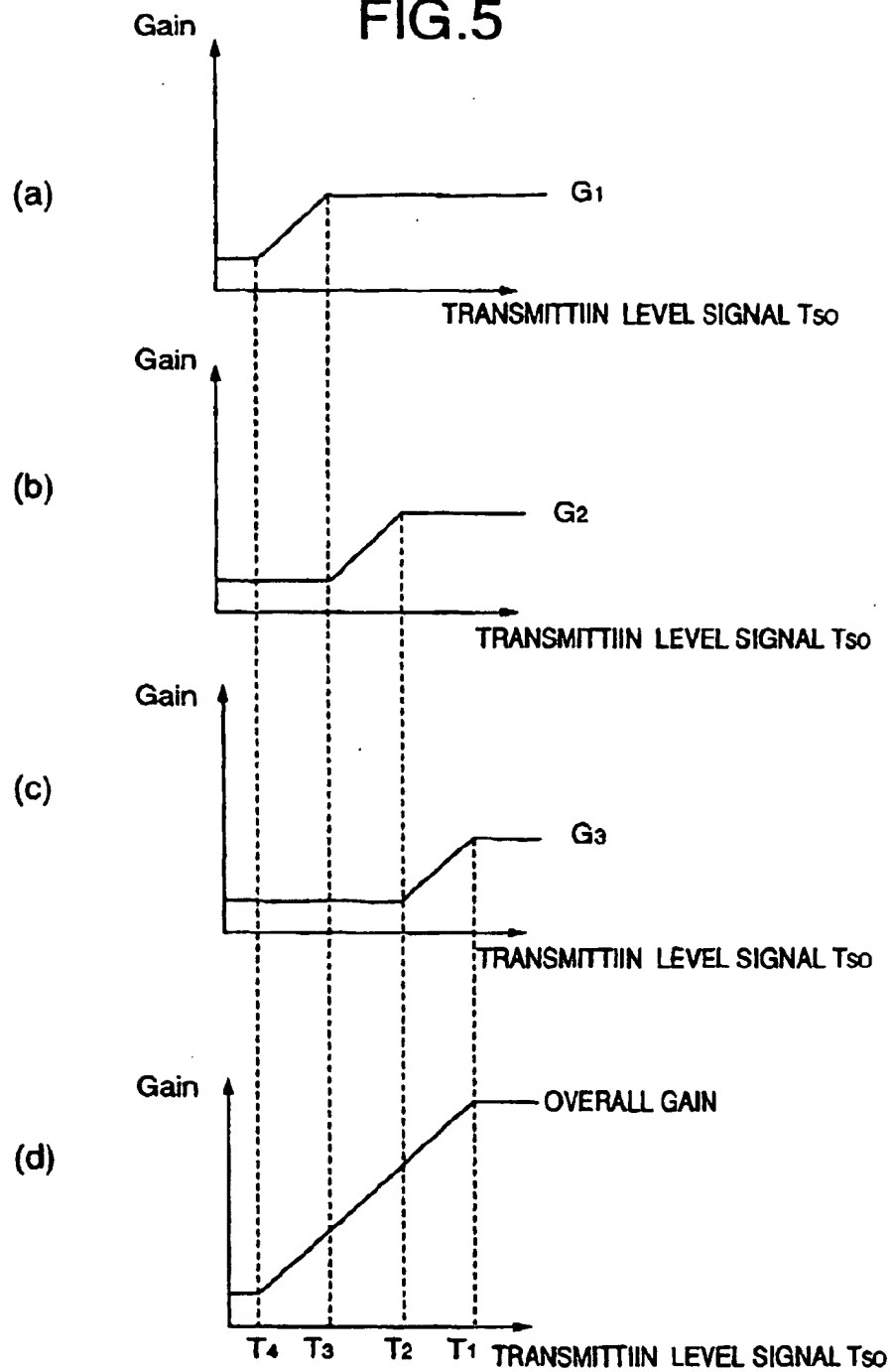


FIG. 6

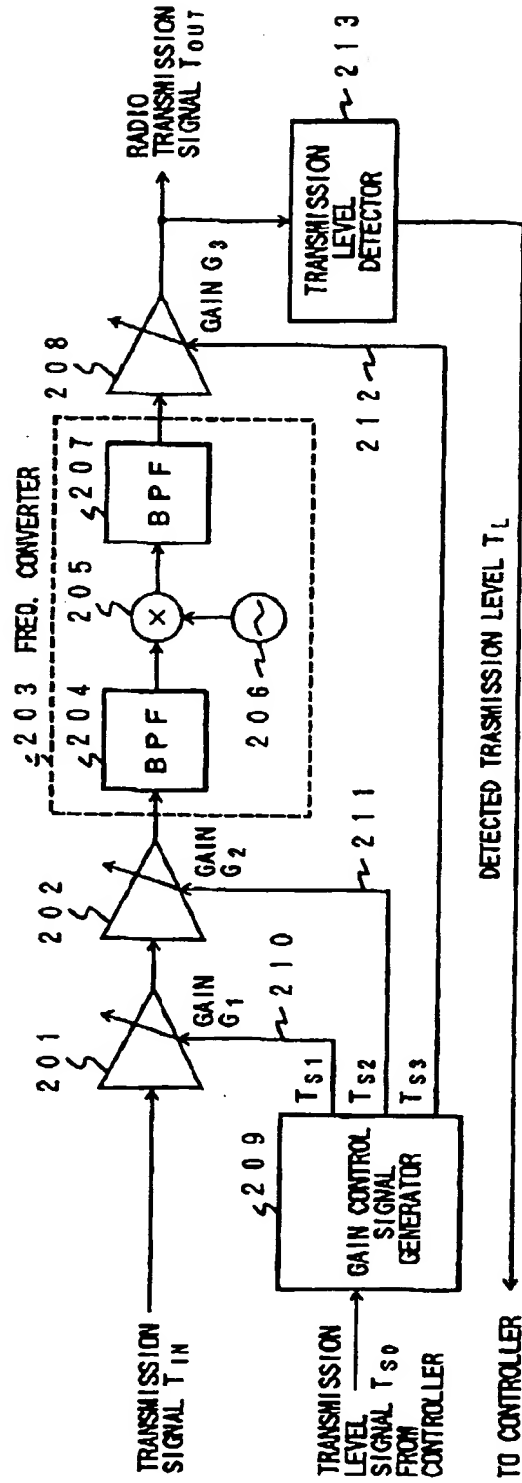


FIG. 7A

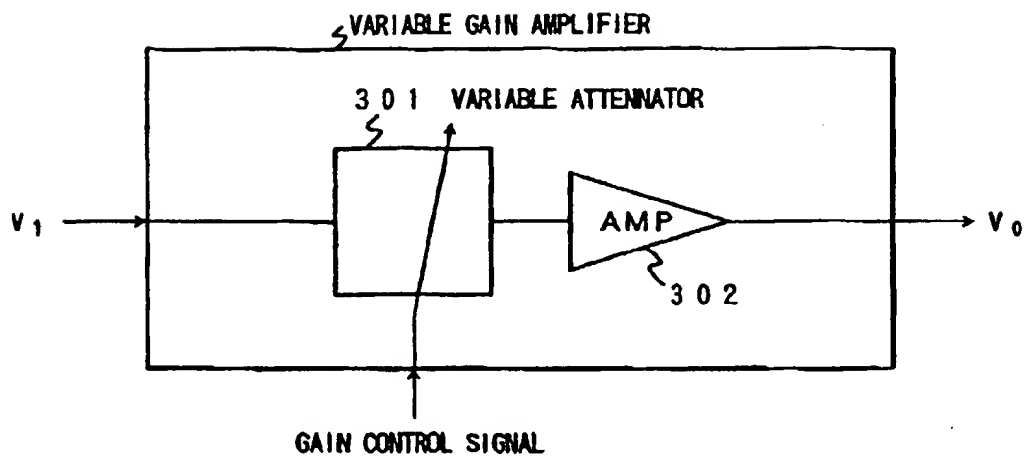


FIG. 7B

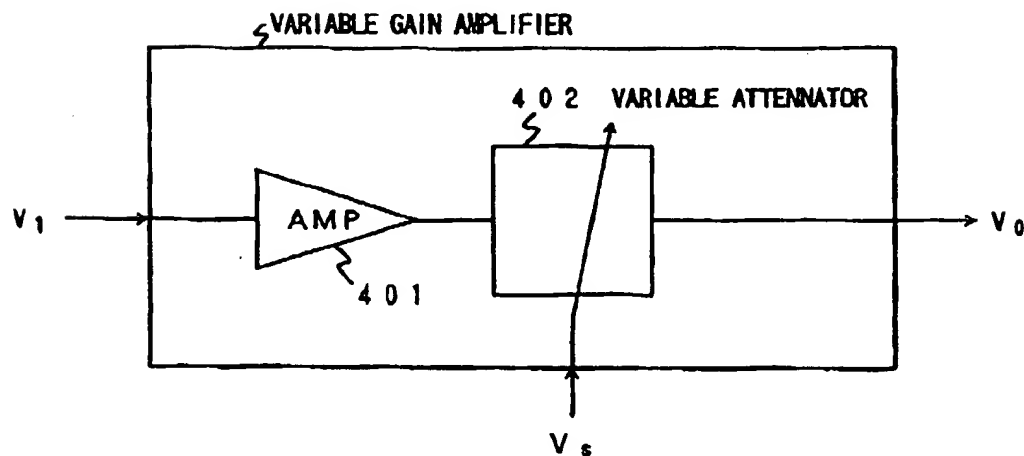


FIG. 8

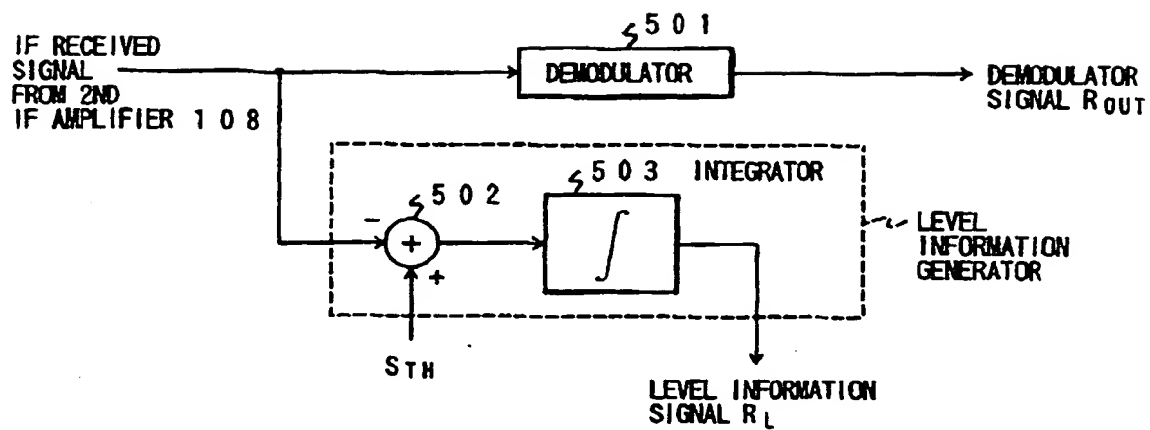


FIG. 9

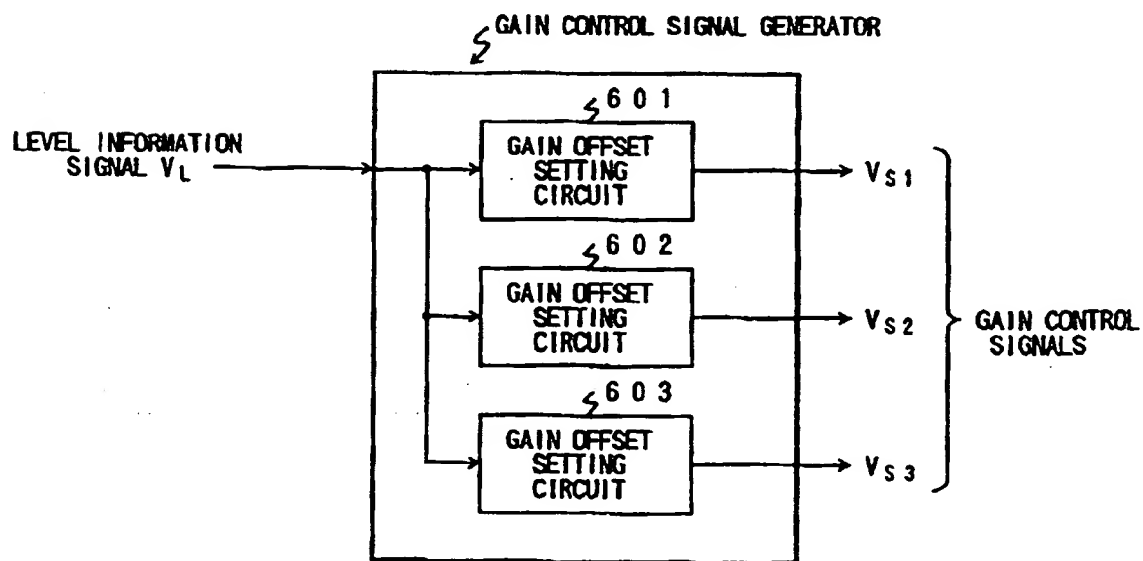


FIG. 10

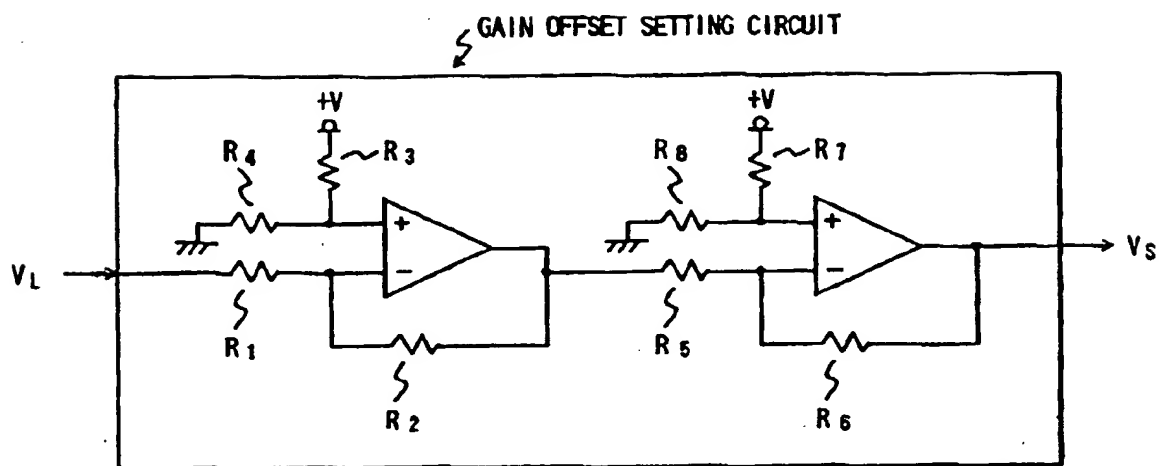


FIG. 11

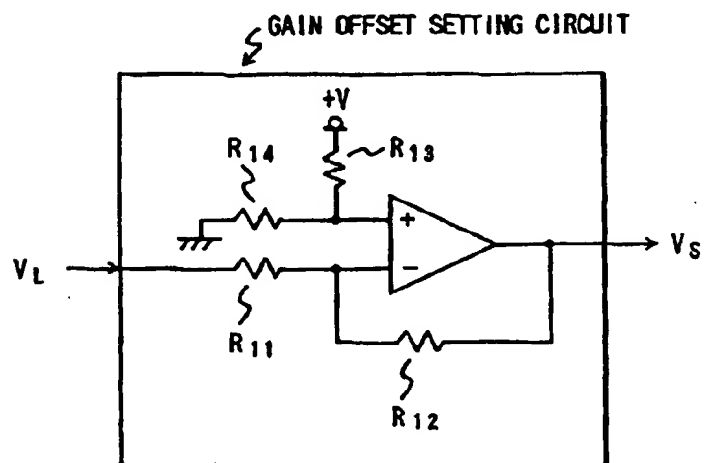


FIG.12

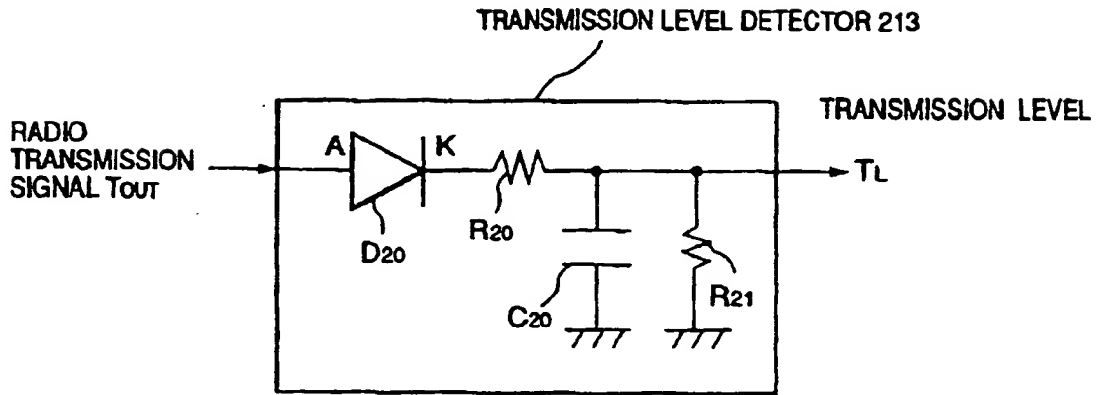
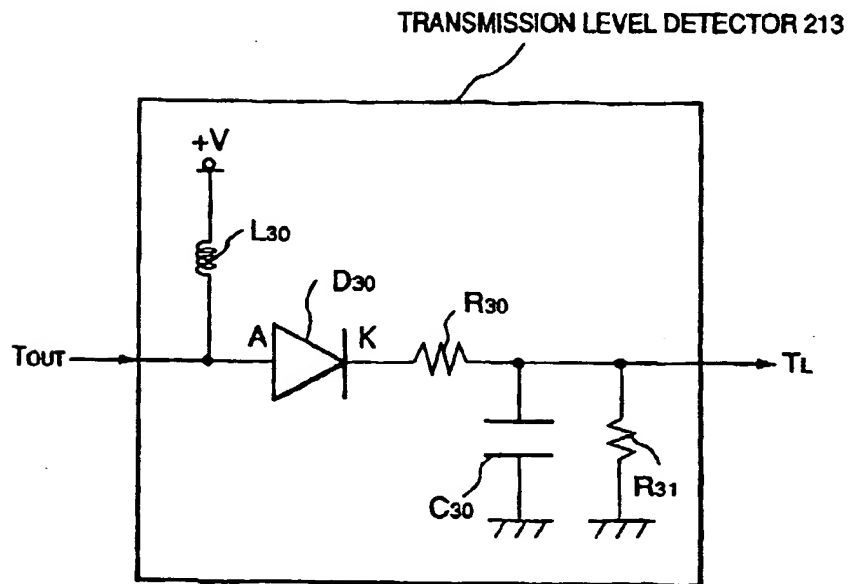


FIG.13





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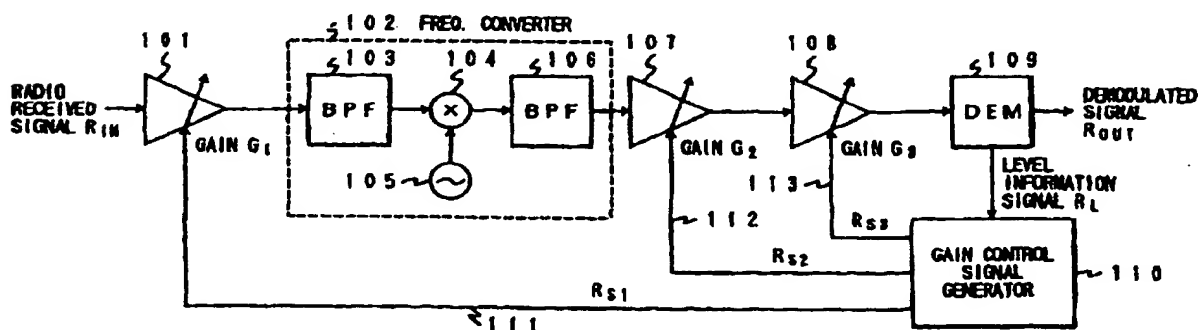
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Tokyo (JP)

(54) **Variable gain control**

(57) In a radio apparatus including a plurality of variable-gain amplifiers (101 and 107-108; 201-202 and 208) and at least one frequency converter (102, 203) which are connected in series, a gain controller includes a plurality of gain control lines (111-113, 210-212) and a

gain control signal generator (110, 209). The gain control lines are connected to the variable-gain amplifiers, respectively. The gain control signal generator individually generates a plurality of gain control signals which are supplied to the variable-gain amplifiers through the gain control lines, respectively.

FIG. 1



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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	PATENT ABSTRACTS OF JAPAN vol. 008, no. 107 (E-245), 19 May 1984 & JP 59 022415 A (FUJITSU TEN KK), 4 February 1984 * abstract *	1-3,5-16	H03G3/30
P,X	NO 96 34452 A (RCA THOMSON LICENSING CORP ;ASCHWANDEN FELIX (CH)) 31 October 1996 * the whole document *	1,3,8, 10,14	
A	PATENT ABSTRACTS OF JAPAN vol. 017, no. 283 (E-1373), 31 May 1993 & JP 05 014088 A (SANYO ELECTRIC CO LTD), 22 January 1993 * abstract *	1-3, 8-10, 14-16	
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A	& JP 05 347522 A27 December 1993		
A	US 4 456 889 A (KUMAR MAHESH) 26 June 1984 * abstract *	1,8,10, 17	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H03G
X	US 5 307 512 A (MITZLAFF JAMES E) 26 April 1994 * abstract *	17	
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 29 December 1998	Examiner Blaas, D-L
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EP 0 797 299 A3 (P1/C01)